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Experiential climate change education: Challenges of conducting mixed-methods, interdisciplinary research in San Juan Islands, WA and Oakland, CA

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ABSTRACT

Transitioning food, energy and water systems for adaptation and mitigation of climate change is a challenge requiring social as well as technological solutions. The best technological solutions will only be effective if combined with behavior changes placing climate change at the forefront of our socio-cultural consciousness. Education is central in creating such a shift. Climate researchers have an important role in aiding the uptake of climate change education in U.S. public schools, where educators are often untrained and uncomfortable teaching the subject. This paper assesses the efficacy of implementing an interdisciplinary, experiential climate change curriculum in school garden classrooms in terms of student climate literacy and teacher professional development. The questions of how to teach and research climate education are explored via a participatory research project with schools in Oakland, CA and Lopez Island, WA. Initial results show improvement in student learning and engagement as well as teacher preparation. Both qualitative and quantitative data are analyzed through student surveys, teacher interviews, and site observation; however, further qualitative methodologies to study *process* of climate and energy literacy development are needed. Specifically, this paper argues for new forms of assessment to capture dimensions of climate literacy including knowledge, engagement, and behavior change.

1. Introduction

The transition to climate-resilient food, energy and water systems is both social and technological, requiring public education in order to translate knowledge from academia to public society and build capacity for implementing climate mitigation strategies. Social science research methodologies, policy mechanisms and educational approaches play a key role in facilitating such a social transition [1,2]. Natural resource management decisions mediate between global and local realities, requiring improved translation of global climate models into locally relevant and actionable information that are understood by local discussion makers. This hinges on developing a climate literate citizenry.

Climate mitigating action is needed at all levels, from international to individual. Current levels of awareness and knowledge about climate change are "insufficient in leading to effective behavioral change" [3]. Leaders in climate change education argue that "based on extensive experience and carefully developed evidence, the emissions gap cannot be closed without also closing the education gap—that is, the gap between the science and society's understanding of climate change, the threats it poses, and the energy transition it demands" [4].

This paper intervenes at the K-12 school level to investigate effective climate education curriculum in public schools. It examines problems of method in two dimensions: methods of delivering climate instruction, and methods of evaluating climate literacy. As a lens to explore climate pedagogy, this paper analyzes a case of experiential curriculum development and piloting in San Juan County, WA and Oakland, CA. Climate change communications, education, and energy literacy literatures offer useful mechanisms for developing students into informed decision makers capable of addressing climate change in their communities [5–8]. These literatures as well as behavior change and environmental education research ground a case study of climate change curriculum intervention.

There is a wide spectrum of beliefs and responses to climate change in the U.S. public, more so than in other countries where climate change is a less politically polarizing topic (often acceptance is higher in developing countries; see [9]). Perceptions in the U.S. range from "alarmed" to "dismissive" according to the Yale Project on Climate Change Communications (YPCCC) Six Americas spectrum [10,53]. Studies such as Six Americas have focused on various adult demographics, with a relatively small amount of corresponding literature on

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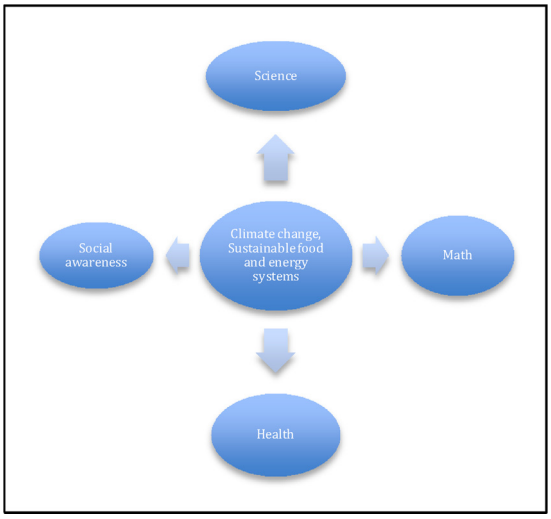

Fig. 1. Curriculum Integration Model.

youth attitudes. New research has just recently followed up on a baseline national measure of youth engagement on climate and energy issues, which indicated very low levels of climate literacy and engagement in the U.S. seven years ago [11]. The follow up survey found that youth engagement continues to be low, lagging behind adults on several key dimensions including willingness to take action [12]. Youth represent the future generation of climate change decision-makers, and are often more malleable to changes in attitude. They are a therefore a promising and important focal point for social study of energy and climate education [13]. A focus on youth must build on the tailored communications strategies proposed in Maibach et al. that allow information to "reach" specific audiences along the spectrum through differentiated instruction. Following from other climate communications scholarship, this curriculum intervention employs narrative "frames," a strategy for delivering contextualized information to an audience in a storytelling format including what the problem is, who is responsible, and what can be done about it [14].

Many strategies for improving climate and energy education are currently being implemented and evaluated [15,16]. This paper explores an interdisciplinary, experiential curricular intervention (Fig. 1) designed to effect change in K-12 climate education. It presents a comparative case study of piloting a climate change curriculum in four middle and high school garden classrooms. The primary aim of this study is to contribute to the literature on effective strategies for climate and energy education, for both students and teachers. It addresses the research questions: 1) What are best practices or effective strategies for delivering climate education curriculum that leads to increases in student climate literacy? 2) How do we currently measure and study climate literacy? And 3) What is the impact on teacher competency and student climate literacy of a 6-week experiential climate curriculum taught in school garden classrooms?

Experiential climate change education engages students in hands-on activities and projects that are solution-oriented alongside the presentation of climate science. This approach builds on the best practices of both experiential learning theory and climate change communications by 1) incorporating personal action accompanied by reflection and 2) fostering hope and positive engagement around a complex global issue. By making climate education experiential, it is more salient and actionable for students rather than paralyzing.

The rest of this first section introduces a food-energy-water nexus framing for the climate education curriculum and the study sites-Oakland, CA and Lopez Island, WA (Figs. 2–3). The second section critiques a single-minded emphasis on quantitative methods in energy/climate education studies, reviews relevant behavior change literature, explores a mixed methods approach to triangulating data collection, and discusses the approach to curriculum development, implementation and assessment. The third section presents results from curriculum piloting in four schools, and the fourth section discusses these results in the broader contexts of a) climate and energy education, b) teacher professional development, and c) behavior change literature. Finally, I conclude with a summary of key takeaways for various audiences, and recommend areas for further research.

1.1. Food-energy-water nexus framing

While the focus of much climate education and societal climate action is around energy systems (i.e. "going solar" and "drive EVs" campaigns), food and agriculture is an important and underemphasized focal area for climate action and education. Food production, transportation, consumption, and disposal are inherently energy- and water-intensive. The global food system is responsible for one third of total human-caused greenhouse gas emissions and 70% of global freshwater withdrawals, due to practices such as fertilizer manufacture, livestock raising, food storage, packaging, and transport [17]. Practiced sustainably, with increased food production near urban center, lower energy and fertilizer inputs, and practices that promote soil carbon sequestration, agriculture could become a significant sink for carbon emissions [17–19]. Building soil fertility can also minimize need for water inputs by holding water more efficiently in the soil. There is an opportunity for multi-sector benefits to be realized through an integrated approach to managing linked food, energy and water (FEW) systems.

Energy use is conceptualized in this study based on its movement through multiple phases and forms. Students receiving the curriculum intervention are taught to think about energy in multiple forms: caloric energy that they receive from food, as well as thermal and electric energy that they consume in their schools and homes. Students engage in education on ways that sustainable, local agriculture can minimize energy consumption through 1) minimizing or eliminating use of fossil fuel inputs, and 2) minimizing transport by selling directly to local markets. Here the concept of "food miles traveled" becomes an illustrative example of energy consumption in the food system chain. Buying local and adopting a primarily plant-based diet are presented as a strategies to minimize food-related energy use and carbon footprint [13,20,21]. Current research on the water-energy nexus also comes in to play through a lesson that highlights how increasing soil water-holding capacity can minimize need for groundwater pumping (and associated energy use), summarized in a recent paper on Mediterranean agriculture [55]. The curriculum includes a carbon footprint calculator activity (based on the CoolClimate Network) where students can quantify how their own food, energy, and water uses contribute to carbon emissions in their location and can compare to global averages.

The food-energy-water nexus paradigm is spreading across higher education institutions. It is also a useful framework for interdisciplinary educational materials aimed at secondary schools. The nexus is aligned with systems thinking practices promoted by the Next Generation Science Standards (NGSS) for K-12 education.

1.2. School case study sites

The pilot schools represent "early adopters" of climate-friendly schoolyards and climate change curriculum, which is not yet widespread in the U.S. [22,23]. The case studies are therefore an opportunity to learn from schools where climate education shifts are already underway, one in a rural agricultural setting and the other school district in a progressive urban environment known for food justice activism. School districts selected for this research are leaders in the national sustainability education effort, places from which best practices can be expanded and disseminated (Figs. 2–3). Both contexts are models of high climate change community awareness [24,25], and

Fig. 2. Map of the San Juan Islands.

taken together provide an urban and rural context for comparative study. If climate change education strategies cannot succeed in these contexts, the chances for their widespread success are low.

1.2.1. Case 1: signs of positive change. San Juan Islands, WA

The San Juan Islands are a national bellwether in the sustainable agriculture education field. They are the top-performing district in Washington state for farm to school activities according to the USDA annual Farm to School Census [26]. The school garden at the Lopez Island School is a thriving agro-ecological example of a ½ acre food production center that meets most of the fruit and vegetable needs of the school cafeteria, producing over 6000 pounds of produce annually. However, in-school efforts on integrated energy and climate change education are a self-identified area for improvement. The Lopez school site became a pilot case for the food and climate curriculum based on results from a prior research study on the district's Farm to School program. Through surveys and interviews with school leaders in spring 2016, I identified climate change curriculum intervention goals in collaboration with teachers, administrators, and students. Follow up focus groups provided the impetus for co-teaching a food and climate curriculum in continued collaboration with the school. In spring 2017, I implemented a curriculum pilot in the Lopez Island Sustainable Practices classroom for students in grades 8–10. The curriculum pilot was accompanied by pre- and post-surveys for student climate change knowledge and attitudes, as well as a teacher interview to debrief the co-teaching model of instruction (discussed further in Section 2 below).

1.2.2. Case 2: Oakland Public Schools. Bringing food and climate to the urban context in CA

Oakland Unified School District (OUSD) is a national leader in the school lunch reform movement. The district is working towards establishing school gardens at all schools, as well as a Central Kitchen and urban farm to provide centralized distribution of locally grown produce to school cafeterias. However, like the San Juan Islands, leadership in school food systems and local sourcing is not yet accompanied by corresponding leadership in climate change education. There is interest at the district and schools level to incorporate climate change into school garden classrooms, but preliminary action steps have yet to be taken. Partnerships are seen as the most desirable and realistic way to incorporate climate change into both science and garden classrooms.

In consultation with the OUSD School Gardens Coordinator and the University of California Cooperative Extension (UCCE) Bay Area Urban Agriculture Advisor, I identified 3 schools for a climate change curriculum pilot in spring and fall 2017. The pilots were assessed with the

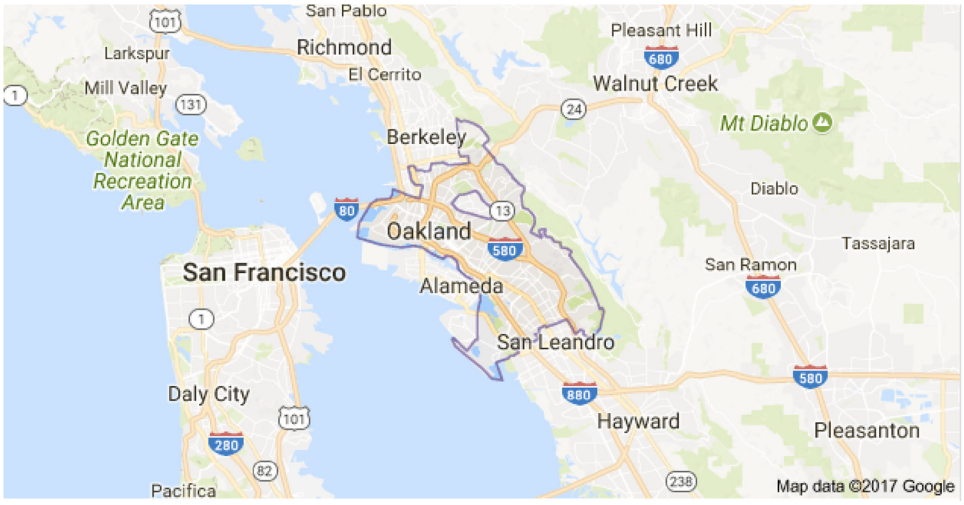

Fig. 3. Map of Oakland Unified School District.

same student survey and teacher interview guide used at the Lopez school. Results from spring 2017 are highlighted in Section 3 below.

1.3. School gardens as a context for climate change education

School garden programs are growing nation-wide as a form of hands-on environmental education, with interdisciplinary benefits of health and nutrition education embedded in the farm to school program model [27]. Meta-analyses of school gardening studies show a wide range of positive results, from academic performance to improved attendance, behavior and emotional development [28]. School gardens are therefore a promising "integrating context for learning" in which to engage youth in climate change education [29]. Teachers have also identified the school garden as "a useful metaphor for the complexity of the climate system" (personal interview, 2017).

Preliminary program evaluations and discussion themes at National Farm to School conferences indicate that the education core element is lagging behind the other core elements: presence of school gardens and local procurement [26,27,54]. These are typically the two areas that farm to school programs focus on—1) establishing a school garden (although quality is highly variable), and 2) procuring food from local sources for cafeteria lunches (i.e. salad bar, seasonal fruit selections; see Fig. 4 for program model). The lack of comprehensive or strategic integration of garden-based education into broader environmental and climate educational contexts leaves many garden educators searching for curriculum independently and not utilizing garden classroom time to its full potential; climate change is a glaring omission in all garden curriculum and evaluative studies examined in for this research project. Furthermore, integration of program evaluation methodologies and consistent tracking of farm to school activities remains a challenge for researchers and practitioners [30,31].

Interviews with educators and students in the San Juan Islands and Oakland Unified School District show that there is a strong interest in incorporating climate change into school garden educational curriculum, accompanied by a need for training in order to do so effectively. Adults often recognize the climate change connection to their farm to school activities (in addition to health and nutrition benefits), but acknowledge that students are not yet taught about these connections. Adding to the education-action gap, teachers often do not feel qualified to teach students about climate change without being content experts themselves.

Building on the school gardens and environmental education literatures as well as personal experience, I developed a climate change curriculum centered around activities in the school garden in order to evaluate whether this represents an effective, experiential climate education strategy. I use a small sample size (four schools) as a cost-effective method to generate further hypotheses on what strategies work for bringing student beliefs, attitudes, and behaviors in line with well-defined social action for climate mitigation. This research is relevant for farm to school practitioners, state departments of education, energy and climate scientists, and those interested in climate change education, both nationally (within U.S.) and internationally. It builds on existing climate, energy and food literacy research and provides insights for how energy and climate research can better integrate with K-12 education development.

2. Methodology and curriculum development

2.1. Literature review- methodologies and behavior change

Hegemonic methodologies in the fields of education and energy privilege quantitative data often at the expense of descriptive or qualitative data well suited to illuminating social phenomena [28,32–34]. This may harm researcher motivation to collect rigorous, exclusively qualitative data (due to inability to attract funding, publish in journals, or influence desired audiences). Such a quantitative bias spills over into the policy realm, as policy proposals often utilize quantitative studies and statistics to motivate their adoption rather than sociological or ethnographic study [35]. This can lead to policies that don't address the root causes of complex phenomena such as food and energy access, water pricing, or environmental injustice.[1] While the reasons for lack of social science input in energy policy are up for debate, the lack of sufficient input itself is clear [36].

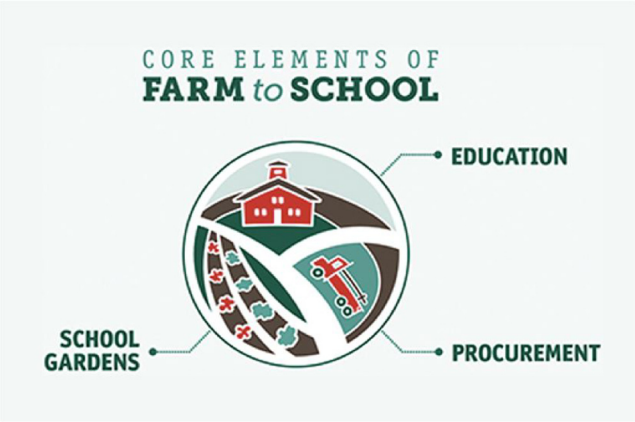

Fig. 4. Farm to School Program Model.

In the case of this research study, collecting unbiased quantitative data on school curriculum interventions for statistical analysis is not always desirable or possible. An overly quantitative approach risks focusing too soon on a limited range of expected outcomes before we fully understand what is important in terms of developing energy and climate literacy in students. Important, complex and nuanced information on interventions is often best obtained through more ethnographic methods and descriptive approaches to data collection. Practically speaking, inconsistent student rosters and attendance complicate quantitative accounting of student learning-hours and tracking in some schools. Middle and high school students are dynamic subjects; they often reveal motivations for behavior and levels of knowledge through spontaneous conversation rather than through more channels of survey participation (which they may refuse to participate in altogether).

Sociological knowledge cannot be reached by quantitative methodology alone, which often relies on silencing the objects of study while placing all analytical control in the hands of the researcher [37]. Qualitative methods and narrative approaches to information gathering are valid methods useful in efforts to uncover process. Knowledge of human behavior and learning processes is precisely what is needed to facilitate a renewable energy and sustainable food system agenda that engages social and cultural norms in reversing climate change. Behavioral economics has much to offer the conversation on climate education, and necessitates a more social science oriented, humans subjects focused approach to research; this field recognizes that "at its heart, global warming is a cognitive and behavior change challenge" [38]. The annual Behavior, Energy and Climate Change (BECC) conference hosted by the American Council for an Energy-Efficient Economy (ACEEE) creates a community of practice around topics such as targeting audiences, trusted messengers, and engaging values in the behavior change process.[2] Through appropriate deployment of both large-

[1] Of course, the policy impact process is complex and relational, mirroring many objects of human subjects research, and no matter how well-founded and rigorous the socio-technical evidence, without visibility and alignment with policymakers agendas research may still fail to achieve policy adoption. See Mazur 2017, this journal, Volume 26.

[2] Session 2C from the BECC 2016 conference focused on Effective Climate Change Communication and emphasized the importance of knowing your audience and using words strategically when conducting education/communication oriented towards behavior change.

N statistical studies and qualitative case studies, with attention to their areas of intersection or divergence, we can advance our understanding of the climate change and energy transformation as social and behavioral, in addition to technological problems.

Ongoing challenges to the inclusion of innovative qualitative and ethnographic research methods present barriers to effectively understanding the social, behavioral components of climate change mitigation [39]. For social researchers, challenges include choosing a level of focus (individual, collective, or institutional), and the intellectual dilemma outlined by Mario Small of whether to "emulate the basic principles of quantitative social science in establishing standards of evidence for qualitative work" [40]. In the context of this climate education intervention, qualitative methods free from quantitative principles (semi-structured interviews and observations) were certainly most useful to understanding the full range of benefits to students and teachers of the hands-on food-climate curriculum. If we are concerned with whether individuals and youth will change their behavior, this is likely something that we must endeavor to observe and participate in as researchers rather than measure objectively.

Links between knowledge and behavior change can be difficult to establish or measure, as many competing influences exist informing individual behavior (social, cultural, interpersonal). This is especially clear from critiques of the information deficit model of behavior change in climate change communications literature [3,13]. When it comes to learning about climate change, cultural identity protection, religion, politics, cognitive dissonance, and more immediate daily priorities all play a role in accepting or dismissing information received. Especially for urban teenagers, climate change can seem like a remote issue distant from their daily concerns. These factors make it very difficult for urban youth to perceive climate change as an actionable, worthwhile cause with which to engage. Methodologically, given the numerous competing influences and analytic frames for interpreting climate change information and knowledge transfer, qualitative methods are best suited to understand the knowledge-behavior (dis)connect. Pedagogically, it is necessary to develop a set of best practices from climate change communication to guide teachers (e.g. tailoring message to audience, developing effective messengers or teachers, using narratives, employing a solutions focus, and engaging in experiential education).

2.2. Curriculum development and implementation methods

Fig. 5 summarizes the chain of activities relevant for this study, which addresses method in two dimensions: pedagogical method (how to teach) and action research method (how to assess/evaluate curriculum). The methods for curriculum development followed processes common to teacher training programs, and incorporate best practices from both critical pedagogy and experiential learning theory. Critical and experiential pedagogy places the teacher(s) as designers of the educational experience, as coaches or facilitators, and students as leaders of their own learning. Both teachers and students have agency to ask and answer questions, and outcomes are necessarily more fluid and less predictable than pedagogy that lends itself to standardized test-taking. Importantly, critical pedagogy implies an embedded project of unearthing and subverting oppression.

The curriculum content is the product of collaboration and feedback with education non-profits and partner teachers, following participatory action research principles. A key partner in the curriculum development process is the nationally recognized non-profit Climate Generation: A Will Steger Legacy. Curriculum implementation followed a co-teaching model. The researcher-teacher partnership draws on complementary domains of expertise: content expertise from the researcher, and classroom management/student dynamic expertise from the teacher. Two symbiotic goals are addressed using co-teaching as an implementation method: 1) students learn climate change from a content expert, and 2) teachers increase knowledge and competence in climate change instruction, allowing future students benefit from a better-trained instructor and serving as a form of professional development. Studies have shown repeatedly that the best way to improve student performance across a range of subjects is to boost teacher knowledge and competency [22,41].

This type of participatory, co-teaching implementation inherently limits ability to statistically analyze a large, representative, or randomly generated dataset of students. It is grounded in social science theory of the qualitative, in-depth case study. Each school required slightly different implementation of the curriculum– in one case snow days canceled several co-teaching sessions, which then had to take place via Skype. Taken as a whole, these four cases shed light on important adjustments that can be made to tailor climate change education interventions to school needs. Pragmatically, meeting unique school needs is a prerequisite for implementing any non-mandatory education intervention in partnership with schools.

2.3. Curriculum content: an interdisciplinary, experiential climate change curriculum

Drawing on climate change communication literature [3,14,42] this research develops an experiential, interdisciplinary climate change curriculum for school garden classrooms. Food is a powerful frame through which to make the climate change problem more concrete and "close to home." The garden, like many outdoor learning environments, provides a useful metaphor of the more complex climate system. The curriculum directly connects climate science to community action and presents an integrated conceptualization of food, energy, and water systems. It teaches students about: 1) managing local *food* production; 2) promoting *water* conservation through planting and soil fertility strategies; and 3) understanding the *energy* systems that provide power, inputs, and transportation for food systems and schools. This systems thinking lens aligns with NGSS (through Crosscutting Concepts related to systems thinking), something that motivates teacher participation when implementing new curriculum. Through local examples and guest speakers, the curriculum connects students to other change makers and empowers them with agency to help build a more sustainable food, energy and water system in their community. Students learn to think of climate change as more than "just" a science problem, but rather as a social problem requiring action and responsibility from all levels of society—individual to international. An experiential curriculum that teaches not just the causes of climate change but also the effects and locally appropriate actions is both rare and needed according to much climate/sustainability education literature [3,22,43].

Each of the six lessons involves students in activities that translate climate-smart agriculture theory into practice. The curriculum provides opportunities for students to learn scientific facts (engaging minds), share personal narratives (engaging hearts), and enact hands-on solutions to climate change via school gardens (engaging hands).Students are engaged in learning about soil carbon sequestration while building compost piles that help sequester carbon in soils. They study the negative effects of elevated CO_2 in the atmosphere globally and then help lower CO_2 locally through increasing plant photosynthetic activity. The pedagogical framework for the curriculum is inspired by Paolo Freire's critical pedagogy [44] and other more current framings of a signature

Fig. 5. Process Diagram.

pedagogy for sustainable food systems education [45]. Both Freire and Valley highlight the need for practical skill building and empowerment of students as active agents rather than passive recipients of information. These and other scholars of critical pedagogy recognize the limitations of more traditional educational frameworks that are didactic, lecture-based, and hierarchical. Through critical pedagogy, student empowerment and agency are focal points. Educators facilitate collective learning experiences that are often subversive in nature and seek to disrupt inequitable outcomes, both environmental and social. Using this lens for curriculum development affects data collection, as educational environments and authentic student input can vary significantly from school to school.

2.4. Curriculum assessment methodology

The study is simultaneously investigating student responses to an experiential climate curriculum, *and* teacher responses to co-teaching as a form of professional development (see Results in Section 3 below). There is a growing need for teacher professional development on the topics of climate and energy especially in light of their inclusion in the three-dimensional learning framework of the Next Generation Science Standards (NGSS). Thus, including this aspect in the research design is timely, and an active area of development for the national Climate Literacy and Energy Awareness Network [56]. The methods used for assessing curriculum efficacy include semi-structured teacher interviews, student surveys (pre- and post- curriculum intervention), and participant-site observation. Triangulation of methods affords opportunity for increased validation of results. Deeper understanding can be gained from a small set of cases on climate change education, and best practices applied to a larger universe of schools seeking to implement climate change education (in garden classrooms or other experiential setting).

Each method has explanatory power to complement the others. Interviews with teachers enable rich data collection, uncover process, and lend themselves to coding analysis for trends between subjects and schools. Interviews followed a six-question interview guide and were semi-structured in nature. Due to the close personal relationships built between teachers and researcher over the six-week co-teaching period, there are limitations (further discussed below) to teacher responses and the degree of positivity expressed towards the curriculum.

Preliminary student surveys provide a baseline for student knowledge and engagement. Compared with post-intervention surveys, this allows for basic statistical analysis to define the effect size in the sample population and whether it is significant. The survey assessment includes 10 knowledge-based questions on climate science and food systems applications, as well as 19 engagement questions asking opinion statements measured on Likert-type scales. This multi-faceted assessment of climate literacy recognize that "knowledge about climate change can be divided into several general and overlapping categories: knowledge about how the climate system works; specific knowledge about the causes, consequences, and potential solutions to global warming; contextual knowledge placing human-caused global warming in historical and geographic perspective; and practical knowledge that enables individual and collective action" [11]. The engagement questions adapt the Six Americas survey questions to capture students' change in engagement towards climate change following the curriculum intervention. Engagement signifies a personal connection with the issue of climate change, and can take place on multiple levels: minds, hearts and hands [3]. Despite best practices employed in survey design, the survey methodology in particular leads to problems of method discussed in Section 4 below.

Participant and site observation over a six-week period captures important features of the school climate, both environmental and social, that help contextualize interpretation of results. The quality of the school garden, behavioral norms, and student informal interactions are all variables of interest for understanding other forms of data collection. For various reasons including difficulty of receiving IRB approval to access minors (vulnerable subjects) for interviews, students were not interviewed in this study, although that would have been a valuable complement to surveys and observation.

None of these methods alone yield sufficient data to advocate for a particular climate education intervention. In combination, they offer effective insights for evaluating climate education-related social research questions. It is important to choose the best method for the context and purpose, while being aware and transparent of the methodological limitations for generalizability [40]. Here, through combining qualitative and quantitative methods, a compelling case can be made to inform climate change education theory and generate future hypotheses for testing. In the emerging fields of climate communications and education, "small, in-depth studies [are] particularly well suited to examine what *does* work in terms of cognitively, affectively, and behaviorally engaging individuals" [3].

2.5. Educational context

Operating in an educational setting, there are many challenges preventing the application of objective, lab-based research methodologies. The approach is participatory, action-oriented, and trans-disciplinary, incorporating both academic and non-academic epistemologies [45,46]. It is also timely, responding to state and national calls for improved climate change education declaring, "now is the moment to elevate environmental literacy as an essential element of a 21st century education… and to establish the leadership, collaboration, strategic partnerships, and necessary funding to ensure environmental literacy for all California students" California Department of Education [47]. The strategic partnerships leveraged in this curriculum development, implementation and evaluation effort include academia, public school districts, and climate education NGOs.

Following initial IRB-approval to conduct preliminary research in Spring 2016 and subsequent IRB approval to expand teacher interviews in Fall 2017, research has been conducted through ongoing consent of school partners. Surveys and semi-structured interviews have been conducted through the relevant school approval processes. Teachers administer surveys to students as diagnostic tools commonly provided at the beginning and end of educational units, and share anonymous student results with the researcher following school-specific protocol.

3. Results

3.1. Lopez and OUSD curriculum assessment

Initial results from curriculum piloting (Spring 2017) demonstrate increases in both student knowledge and engagement with climate change. Climate literacy was assessed in a holistic sense, including student knowledge of appropriate individual and collective actions (not just the mechanistic causal process of climate change). As shown in Table 1, student climate change knowledge scores increased by 15 percentage points on average over the course of the six-lesson curriculum with a reduction in variance and statistical significance ($p < .001$). The largest gains were seen in Lopez and Oakland 2. Results are summarized in Tables 1 and 2 and broken down by question in Fig. 6.

Attitude and engagement questions revealed higher levels of concern along the Six Americas spectrum than the national average (see

Table 1
Aggregate Curriculum Survey Results.

	Pre Survey	Post Survey
Mean (% correct)	53	68
Variance	5.6	4.26

Table 2
Results by School.

	Lopez	Oakland 1	Oakland 2	Oakland 3
Pre (% correct)	53	49	59	21
Post (% correct)	69	58	75	30

Fig. 7). The first 10 questions were adapted almost directly from the Six Americas survey, with some modifications for student-friendly language. An additional nine questions were added dealing specifically with food systems, behavior and climate change. Based on the first 10 questions, students were categorized into the six segments from alarmed to dismissive, with almost all students falling in the top three categories (alarmed, concerned, and cautious). Students demonstrated an overall increase in engagement although this was difficult to measure with precision due to inconsistencies within student response patterns, and different numerical scales used for each question (1–4, 0–4, 1–9, etc.). However, a preliminary analysis (Fig. 8) is valid for determining directional effect arrows and assessing whether pilot programs should continue, and thus were used for this evaluation. Precision could be added in future iterations by simplifying answer scales so they are consistent, and then quantifying student attitudes on a numerical basis. The survey was a bit long to hold student attention, and survey fatigue was a confounding variable in some cases. Work is underway by the Yale Project on Climate Change Communications to create a four-question survey version for teens, which will be a valuable improvement for future studies.

Informal observations and conversations reveal a latent curiosity and interest among youth in learning more about climate change. A commonly expressed sentiment, especially at the outset of the curriculum intervention, is that climate change is an important issue that students feel they should know more about. This is mirrored in national statistics reporting that American teens recognize their limited understanding of climate change, and 70% say they would like to know more about the subject [11]. Improvements should be made to the curriculum as a result of student dialogue and feedback, such as allowing more independent and group work by students, engaging them in a process of discovery.

Post-intervention teacher interview themes revealed a widespread appreciation of co-teaching as a mechanism for delivering climate change instruction. All teachers interviewed expressed enthusiasm for having a content expert present to deliver instruction while teachers focused on classroom management and student behavior. Teachers were able to learn from the experience and expressed desire to replicate elements of the curriculum on their own in the future, thus meeting one of the process-specific goals of the research. Interview responses also revealed a common theme of searching for hope and action amidst the daunting reality of climate change; the garden and classroom were often identified as key arenas where hope and solution steps exist. Key quotes from interviews are highlighted in Table 3 below.

These results, in particular the challenges highlighted by teachers, closely match national findings on climate change education. In a recent national review of science teachers, the first nationally representative study of science educators to focus on climate change, fewer than half of all teachers reported any formal coursework on climate change, and over two thirds expressed interest in professional development opportunities [22].

Partnerships (with local NGOs, universities, and community groups) emerged as a key feature enabling success of climate, food, and energy education in schools. Partner organizations and individuals are able to provide infrastructure support, outdoor learning environments, guest speakers to reinforce climate education units, and program evaluation assistance. A partnership model is commonly deployed in public schools seeking to meet diverse student body needs, but is often site-specific; inevitably, some schools benefit more than others. In one high school in Oakland (mentioned by interview subjects but not included in this curriculum intervention), partnerships with various non-profits and businesses (restaurants and local CSA) enabled the establishment of an exemplary 1-acre farm and permaculture garden, with numerous benefits: 1) student employment, 2) nutrition and health education, and 3) potential for more impactful climate change education due to the larger scale of local food production and associated benefits demonstrated. Questions of how to scale impact at the district or state level and education policy implications are discussed below.

4. Discussion

Results of this analysis are both reflexive on the methodologies used, and responsive to the research gap in connecting climate change communications to behavior change. There is much skepticism over whether information alone is enough to yield climate friendly behavior change, and definitions of environmental and climate literacy often contain a “take action” component [3,7,11,13,47]. It is recognized that “education for action requires more than scientific literacy; it must integrate concepts and dynamics across disciplines and in ways that address affective, social, and cultural forces—a challenge that can be met through effective and evidence based climate change education” [4]. It is an educational best practice to make climate change relevant and actionable within students’ daily lives, in order to promote information retention and adaptive behavior change. I turn now to discussing the results in terms of both student and teacher outcomes.

4.1. Student learning outcomes

Interpreting the results, with positive but incremental gains in

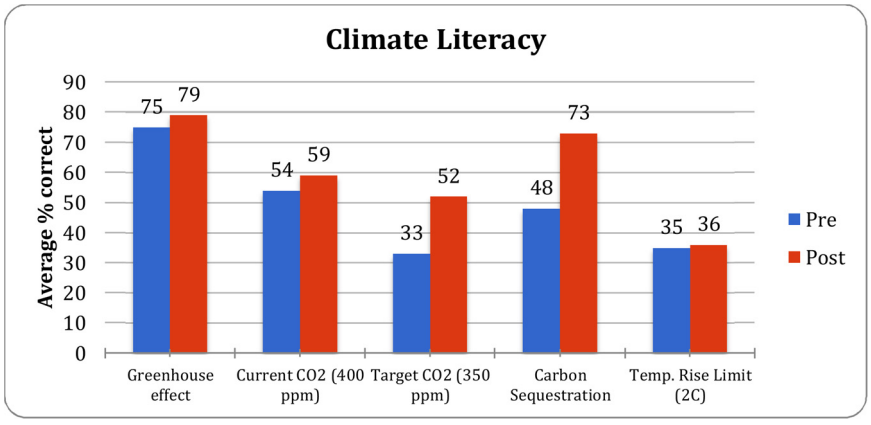

Fig. 6. Climate Literacy by Question.

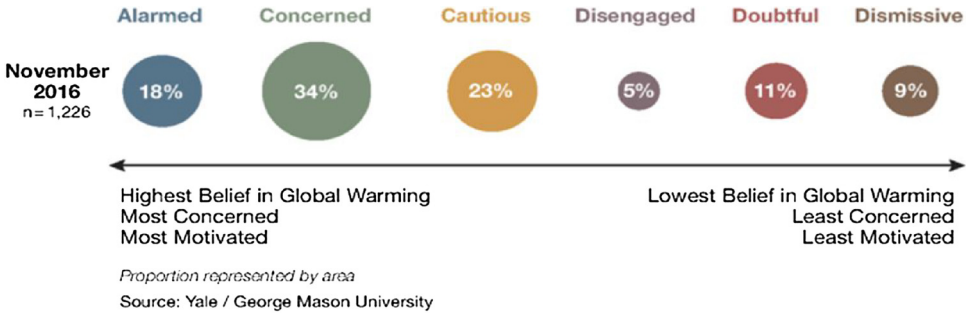

Fig. 7. Six Americas Segmentation.

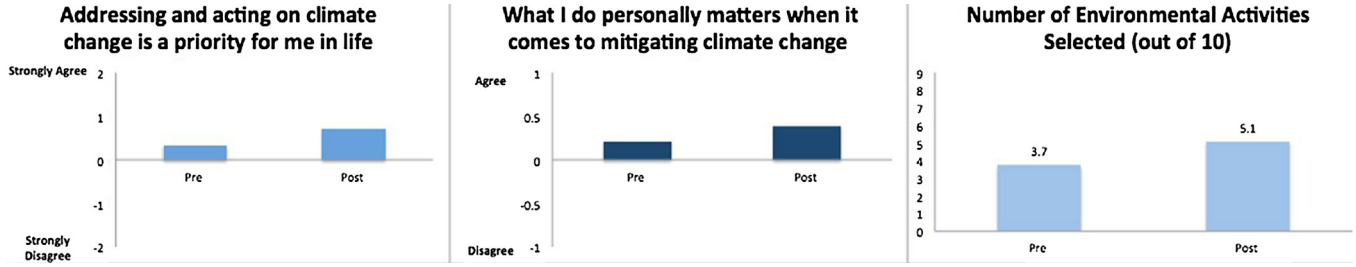

Fig. 8. Student Engagement Increases.

Table 3
Teacher Interview Responses.

	Teacher Response
Co-teaching model	"One of the things I like about having co-teachers is that it just means more to [students], they listen better… and I learned from the experience and I can begin to weave it into what I do and teach."
Climate change instruction	"A lot of climate change is out of control and scary for kids, but to teach while doing something positive helps balance that out."
Challenges	"Lectures would be impossible to do on my own; need videos or further guidance for independent teaching."

student learning and engagement, motivates a return to the problems of method grappled with in this study. The central problems with the methods used revolved around the student survey methodology. It was both extremely difficult to control student attendance and survey environment across multiple classrooms, and impractical to analyze the pre- and post-results for statistical significance given the small samples sizes; if anything, the survey results were positive indicators that the curriculum was not a waste of time, but beyond the basic fact that students improved their results, which is very much to be expected based on any curriculum intervention, the survey did not shed much light on whether experiential learning strategies were *more* effective than other climate education pedagogy. In order to understand this important question, comparative analysis is needed between didactic and experiential approaches to climate education among a constant student demographic. This will be the focus of future study using the curriculum designed for this study. Additionally, ways of assessing student response beyond surveys should be further developed- including student interviews (where possible), oral debriefs, and written reflections. Students did express positive reactions to the outdoor gardening curriculum, and more interest and awareness in incorporating climate friendly eating and gardening patterns into their daily lives (in some cases expressing desires to become vegetarian), but these reactions were captured in the ethnographic observational methodology, rather than the multiple choice student surveys.

It is important to note that much is being measured in student post-surveys besides the change in student knowledge. Embedded variables include the efficacy of instruction, skills of the co-teachers, and learning environment of the school and garden that might promote or discourage student attentiveness and engagement. These must be disentangled and understood through other social science methods. The nationally representative climate literacy survey tools are not necessarily the most valid or worthwhile approach to assessing the efficacy of an experiential climate change education tool. To truly understand the utility of this intervention, it matters less whether students have memorized the ambient CO_2 concentration and more whether they are motivated to gather more information on climate change independently, have some context within which to critically interpret future information on climate, and are motivated to align individual behaviors with more climate-friendly actions.

Additionally, when it comes to evaluating student learning gains, further work is needed to evaluate the retention of knowledge gains, by following up with the same cohort of students after 6 months, 1 year and beyond. This will add strength to claims that hands-on learning in school gardens improves student retention of information, generally [28] and whether behavioral changes expected from experiential learning curricula manifest and maintain over time [43,48].

4.2. Teacher professional development

The impact on teachers participating in the curriculum co-teaching was overwhelmingly positive, and important to contextualizing impact on students. The more enthusiastic and knowledgeable teachers became about climate change connections in the school garden, the more engaging lessons became for students. While results recorded from teacher interviews are subject to a positive bias due to the positive relationship between teachers and researcher, these results echo other teacher responses to climate education professional development (PD) nationwide. It is well established that teachers are in need of professional development in order to teach an unfamiliar subject with confidence and competence, and several national leaders in climate education are addressing this need (CLEAN, 2018) as well as states such as Washington through recent funding for teacher climate education PD [49]. Climate Generation: A Will Steger Legacy has offered an annual climate education Summer Institute for teachers since 2006, drawing in 50–100 teachers annually from across the country for three days of workshops and activities that are directly translatable into their

classrooms. Having a climate science "expert" in the classroom to co-teach a climate change curriculum for the first time is another promising form of PD explored in this study. Teachers reported a high level of comfort that makes implementing something new much less daunting.

4.3. Results by context- San Juans and Oakland

I grew this curriculum evaluation study out of previous research relationships where a collaboratively identified future outcome was a food and climate curriculum, as summarized in the Methods section above. Lopez is a small island community where sustainable agriculture, support for clean energy, farm to school programs, and climate change awareness are shared values. This cannot be ignored when evaluating the social-environmental behaviors of schools in the San Juan Islands. Stakeholders at the Lopez school considered the pilot successful and worthy of continuation. Students selected a biochar experiment as a class climate action project, and will be applying biochar to test plots in the school garden to compare with non-treated plots (observing effects on yield, plant health, and soil carbon levels). This case adds to the body of literature on successful climate change engagement strategies meriting replication in other sites. The fact that students responded positively in this context is a first-degree mark of success for the curriculum intervention, and higher degrees would be met through success in more resistant communities.

Students in Oakland also exhibited a high level of concern and engagement with climate change. However, Lopez and Oakland students did not perceive climate change as a daily or immediate threat; rather, it was still perceived as something far off and global rather than a local concern. Students in Oakland had more immediate food-security and job-related concerns that focused attention on school gardening more towards meeting short-term goals (getting enough healthy food to eat, gaining job skills) rather than long-term goals (fighting climate change). Food insecurity exists on Lopez, but not to the same degree as it does in Oakland, where it is a widespread problem coexisting with food sovereignty and community divestment issues [50]. Linking climate change with green career pathways in clean energy or sustainable agriculture was a more transformative strategy in Oakland classrooms to capture student interest than on Lopez, students were less worried about finding a job after school.

Relating climate change to local or current events is an effective mechanism in both contexts. Discussing climate change in light of the particularly severe 2017 hurricane season, or the devastating Northern California wildfires that introduced the worst air quality on record in the Bay Area, significantly boosted student attention. More students participated actively in the discussion and internalized the value of trees, plants, and school gardens as "climate solutions" in light of these events.

High school students in Oakland were more receptive to learning about climate and energy issues that were beyond their "backyards" than middle school students, especially when garden activities were framed as items to include in college or job applications (through forming school garden clubs or expressing desire to study climate justice in college). Middle school students were more easily distracted by their peers and behavioral dynamics that detracted from the learning environment. Therefore one of the recommendations from this research is to focus on high school experiential education as a strategic leverage point, preparing youth for climate action as independent adults in whatever career pathway they take.

The cases presented are distinguished by the fact that these schools are more advanced than the national average when it comes to establishing school gardens and supporting climate change education. However, as Small points out, "in case studies, rare situations are often precisely what the researcher wants" [40]. Learning from a small and growing set of cases, a model can be built for integrated food, energy and climate education.

4.4. Recommendations for future applications

While climate change education will manifest differently in different cities across the U.S., there is no need to reinvent the wheel in each city and school district. Several hypotheses can be presented to guide future research and contribute to theory-building work on climate education—following Daniel Bertaux's methodological process where hypotheses are generated at the end of an extended period of fieldwork and data collection:

1 Students will retain information best if they engage actively in hands-on projects related to climate change content. Solutions-oriented activities including (but not limited to) those in a school garden or other school infrastructure project are best suited to improving climate literacy for the largest number of students.
2 The school garden context is a relevant proxy for any outdoor learning context where experiential climate change education can take place; using other settings such as national parks, preserves, or renewable energy project development sites would serve a similar purpose in delivering impactful, location-specific climate change education.
3 Using multiple strategies in combination is effective for communicating climate information: outdoor learning, computer-based learning, videos, storytelling and field trips lead to high levels of student engagement.
4 Personal (and family) narratives and positive frames for climate change information are important to youth first learning about a subject this complex and potentially depressing.
5 Co-teaching is a useful form of climate education professional development because it harnesses complementary expertise from teachers and researchers in order to benefit students in the long run. Partnerships between climate researchers in academia and K-12 teachers should be scaled up.
6 Appropriate assessment methods linked with experiential learning objectives must be developed for climate and energy literacy curricula, moving beyond a simplistic multiple choice post-test to determine if processes of competency development have been realized.

The skilled deployment of narrative and storytelling within climate education in particular is a strategy worth further exploration through in-school studies and program evaluations. A previous issue of this journal on Narratives and Storytelling in energy and climate change research (ERSS vol. 31) highlighted the strengths of this unconventional analytic approach that treats stories as data objects of study, though none of the cases dealt with stories deployed to a youth audience within the context of K-12 climate education. Such work is being piloted in several schools where climate change curriculum is presented within humanities and social studies classes, but the only known examples are occurring in private rather than public schools. Further exploring the impact of storytelling integrated with the scientific presentation of climate change will require development of alternative assessment methods, described below.

In future work, usage of qualitative or descriptive assessment methods for measuring increases along the multiple dimensions of climate literacy and sustainability competencies will be valuable. In this way researchers can begin to disentangle important causal variables among many distinct avenues affecting an individual's climate change knowledge and perceptions. Longitudinal evaluations of students involved in climate education are an important next step to better understand longevity of desired behavioral changes. Furthermore, experimental research designs that compare experiential vs. didactic, information-only climate curriculum interventions would aid in validating the efficacy of experiential learning as a climate education strategy.

5. Conclusion

Given that public education institutions are central social vehicles for creating an informed and empowered citizenry, examining the effects on public school students and teachers of a climate education intervention is an important contribution to the social study of energy and climate. At the international level, the UN is championing the need to improve climate education and better integrate research into practice (COP 21, [6]).

While it is difficult to grapple with two problems of method simultaneously in a research study (in this case, pedagogical methods and action research methods), it is increasingly inevitable as energy and climate research responds to calls to be more interdisciplinary and interactive between academic researchers and real world energy and climate problem-solvers. It is possible given insights from this research endeavor that climate education pedagogy *and* methods for evaluating and scaling can co-develop as each feeds back into the other.

Ethnographic methods are not often prioritized, but here I find evidence that they should receive greater emphasis and inclusion in climate and energy literacy evaluations. Developing qualitative assessment strategies that draw on ethnographic methodology for measuring competency development is a promising area for future work. Such assessment strategies might include written teacher feedback, peer evaluations, student self-reflections, and whole-class oral debrief. These would better capture school-to-school variation and complement the standardized student survey. Climate education assessment strategies are rapidly evolving to capture the full spectrum of outcomes related to such interventions (student outcomes, teacher competencies, intergenerational transfer, etc.). This will inevitably lead to difficulty in terms of comparability of results from school to school, an inherent tension in scaling up qualitative research studies. The evolution of assessment methodologies will ideally parallel active trends in sustainability learning literature, moving towards descriptive and holistic rather than multiple-choice evaluations of student learning outcomes [43,51].

Experiential climate change and energy education is a nascent field with great potential, where the school garden is one context for experiential environmental learning while many others are possible. Bringing the “think global, act local” paradigm into the classroom is a key strategy underlying this initial curriculum, as is the experiential learning cycle incorporating both action and reflection elements. The findings of this study also point towards the value of partnerships between higher education institutions and secondary schools, such that climate education can be implemented and evaluated in a more integrated, participatory research process. Lessons learned during curriculum piloting are more quickly identified, corrected and scaled through the help of academic program evaluators.

Energy systems studied in this research take many forms, with a focus on human interaction with food, energy and water systems. By emphasizing and teaching local forms of food production and consumption, this curriculum intervention seeks to re-localize climate stewardship and in doing so reduce the energy footprint of goods and services.

These results are most relevant to school districts and national climate change education initiatives seeking to build the capacity necessary for future generations to adapt to and mitigate climate change, as well as those involved in evaluating climate education interventions. There are several non-profits already engaged in this work, and an office with the National Oceanic and Atmospheric Administration devoted to climate change education, but too often work is done in isolation. Climate and energy education requires partnerships between climate scientists in academia, policy makers in government, NGOs and public schools to achieve maximum impact.

Energy and climate research articles frequently highlight in Conclusion sections that corresponding outreach, education, and “science usability” translation must occur to bring basic science into practice in social settings. Climate modeling and technology innovation alone will not solve the climate crisis. Emergent participatory and co-production methodologies in the social sciences are essential to understand, implement and scale the social transformation necessary to adopt clean energy technologies, local food systems, and water-conserving livelihoods. Social transformations are highly contextualized, necessitating culturally and geographically relevant framings of climate change and clean energy transitions. Strategic communications with an eye towards larger impact can achieve large engagement gains by mobilizing opinion leaders or youth [11,52]. Schools and youth represent an underutilized resource in the climate and energy behavior change initiative. Schools are natural learning centers and community gathering spaces, and students can serve as motivators for adult/family engagement, a focus of the emerging intergenerational transfer literature. It is the aim of this research project to promote additional study and international discourse on energy and climate change education, with climate researchers engaging in K-12 education and practitioners contributing key insights to the climate education improvement process. Climate education is an equity and justice issue. Students today must be well trained and prepared to lead the radical energy transition of tomorrow.

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Conflicts of interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.erss.2018.06.023.

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